Next-Generation Tropical Cyclone Model

Richard M. Hodur
Naval Research Laboratory
Monterey CA 93943-5502
phone: (831) 656-4788 fax: (831) 656-4769 e-mail: richard.hodur@nrlmry.navy.mil

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LONG-TERM GOALS

The long-term goal of this project is to develop a robust and hardened high-resolution air-ocean coupled tropical cyclone (TC) data assimilation and prediction system that is able to assimilate the wide variety of available in-situ and remotely-sensed observations in order to analyze and predict TC structure and intensity changes in an operational environment. Significant gains have been made in TC track prediction over the past three decades. This considerable achievement is due, in large part, to the steady improvement of numerical models, especially the global scale prediction systems, and the judicial utilization of multi-model ensemble results. In contrast, the TC intensity forecast by numerical models has shown very little improvement during the same time period, and remains a formidable forecast problem. Advanced statistical prediction models nowadays are able to predict the trend for intensification, but as statistical tools, they inherently cannot predict the rapid intensity changes, as evident in Katrina and Rita of 2005, and other tropical cyclones. It is generally accepted now that while advancements in data assimilation and modeling have resulted in better analyses and predictions of steering flows, the processes that affect the structure and intensity of tropical cyclones are much more difficult for current numerical models to capture and reproduce. Physical processes in tropical cyclones that can affect their structure and intensity include enthalpy and mechanical interchanges with the underlying ocean and land surfaces, shallow and deep atmospheric convection in the convectively unstable tropical atmosphere with vertical and horizontal wind shears, and internal multi-scale non-linear dynamic interactions. Current prediction systems have been shown to be able to reproduce rapid intensification in case studies involving complex upper tropospheric and oceanic conditions in a carefully conducted simulation mode (e.g., Hong et al. 2000).

OBJECTIVES

The objective of this project is to develop and validate a next-generation tropical cyclone (TC) model that can analyze, initialize, and predict TC position, structure and intensity, using a high-resolution (<3 km) air-ocean coupled mesoscale modeling system. The development will leverage emerging data assimilation and modeling techniques as well as observational results from the scientific community to build upon existing modeling capabilities.

APPROACH

Our approach is to integrate emerging data assimilation and modeling techniques, as well as recent observational results, into the existing framework in the Coupled Ocean/Atmosphere Mesoscale

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14. ABSTRACT
The long-term goal of this project is to develop a robust and hardened high-resolution air-ocean coupled tropical cyclone (TC) data assimilation and prediction system that is able to assimilate the wide variety of available in-situ and remotely-sensed observations in order to analyze and predict TC structure and intensity changes in an operational environment. Significant gains have been made in TC track prediction over the past three decades. This considerable achievement is due, in large part, to the steady improvement of numerical models, especially the global scale prediction systems, and the judicial utilization of multi-model ensemble results.

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Prediction System (COAMPS®[1]) for applications to the analysis and prediction of TC position, structure, and intensity. Specific technologies that will be developed and integrated into COAMPS in this project are physical processes and TC analysis techniques. This project will leverage recent research conducted on the physics of the surface and boundary layers in the recent ONR-sponsored Coupled Boundary Layers/Air Sea Transfer (CBLAST) project. In addition, we will leverage work performed over the past 2 years to integrate COAMPS with other physical parameterization schemes in the Weather Research and Forecast (WRF) repository, including the physics in the WRF-Advanced Research WRF (WRF-ARW) model developed at the National Center for Atmospheric Research (NCAR), and in the WRF-Nonhydrostatic Mesoscale Model (WRF-NMM) developed at the Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP).

WORK COMPLETED

The following work was completed in FY07:

The NRL Atmospheric Variational Data Assimilation System (NAVDAS) was modified for tropical cyclone analysis. The modifications include (1) consistent feedback of analysis increments from the COAMPS inner meshes to the COAMPS outer meshes, (2) correctly identifying the location of moving meshes in the data assimilation cycles, and (3) re-locating the first-guess tropical cyclone circulation to its observed position.

The following three changes were made to the COAMPS surface layer parameterization. First, an off-line surface layer model was built that contains surface layer schemes from four widely used numerical weather prediction models: COAMPS, GFDL, WRF ARW, and WRF NMM. COAMPS simulation results of Isabel (2003), which captured the track, intensity, and structure of this storm very well, are used to drive the off-line surface layer model. The input fields for the model are the bulk Richardson number, sea surface temperature (SST), surface pressure, and the 10 m temperature, moisture, and wind fields. The output from the model includes, among other variables, the roughness length for momentum, and the transfer coefficients for momentum, heat, and moisture. The main advantage of using this off-line surface layer model is that the 4 different surface flux schemes use exactly the same set of input data and the differences in the surface transfer coefficients comes only from the differences in the schemes, without other complicating processes. Our understanding of the strengths of each the 4 surface layer schemes through use of the surface layer model for strong winds is then used to modify the COAMPS surface scheme for tropical cyclone (TC) forecasts. Second, recent observations from the Coupled Boundary Layer/Air-Sea Transfer – Hurricane component (CBLAST-Hurricane) experiment and laboratory tank experiments under high winds were incorporated in the modified COAMPS scheme for a more realistic representation of the momentum, heat, and moisture exchange processes at the air-sea interface. Third, high-resolution (3-5 km) COAMPS simulations of 10 TCs over the past 4 seasons (2002, 2003, 2004, 2005) were carried out to evaluate the performance of the new COAMPS surface scheme on TC structure and intensity forecasts.

RESULTS

The upgrade to NAVDAS significantly improves the analysis of the TC position and structure. As a result, the COAMPS tropical cyclone track forecast is significantly improved, particularly in the early

[1] COAMPS® is a registered trademark of the Naval Research Laboratory.

forecast period (Fig. 1). Furthermore, NAVDAS now can be used in the COAMPS warm start runs with moving grids.

The transfer coefficients for momentum, heat, and moisture as a function of the 10-m wind speed calculated from the 4 surface layer schemes are depicted in Figs.2a-c. There is large disparity in these coefficients between the 4 schemes, especially for winds exceeding 30 m s^{-1}, and the difference becomes even larger with increasing wind speed. The momentum transfer coefficient (C_D) from COAMPS (black line A in Fig.2a) lies in the middle of the range of the 4 schemes. In the COMAPS new scheme (black line B), C_D levels off when the 10-m winds exceed 33 m s^{-1}, reflecting the new findings from both field observations and tank experiments. The heat and moisture transfer coefficients in the COAMPS scheme (black line A in Figs.2b and 2c) have the lowest values among the 4 schemes examined. This is one of the contributing factors for COAMPS to tend to under-estimate TC intensity since the low exchange coefficients limit the moisture and heat fluxes from the ocean surface, which is the main energy source for TC development. The COAMPS new surface layer scheme generates larger exchange coefficients for both heat (black line B in Fig. 2b) and moisture (black line B in Fig.2c), consistent with the CBLAST observations.

We are using COAMPS as a test bed to systematically examine the sensitivity of TC intensity and structure forecasts to a wide range of values of exchange coefficients from these schemes. In a Hurricane Katrina (2005) simulation using 3-km grid spacing in COAMPS, the run with the COAMPS new scheme (black line B in Figs. 3a and 3b) significantly improves the intensity forecast compared to the COAMPS scheme (black line A in Figs.3a and 3b) in both the mean sea level pressure (MSLP) and surface maximum wind speed fields. The difference between these two runs after 66 h in the simulation reaches 24 m s^{-1} for the wind speed and 38 hPa for MSLP. The high sensitivity of TC intensity to the specification of the surface exchange coefficients is also revealed by comparing the results from the COAMPS simulation using the WRF ARW surface scheme (red lines in Fig. 3) with those using the COAMPS new scheme. The difference becomes significant as early as 30 h into the simulations. One possible reason for this difference is that the WRF ARW scheme increases the heat exchange coefficient much faster with increasing wind speed (red line in Fig. 2b). We will continue study and improve the representation of the physical process for the surface exchange coefficients as more observations under high winds become available.

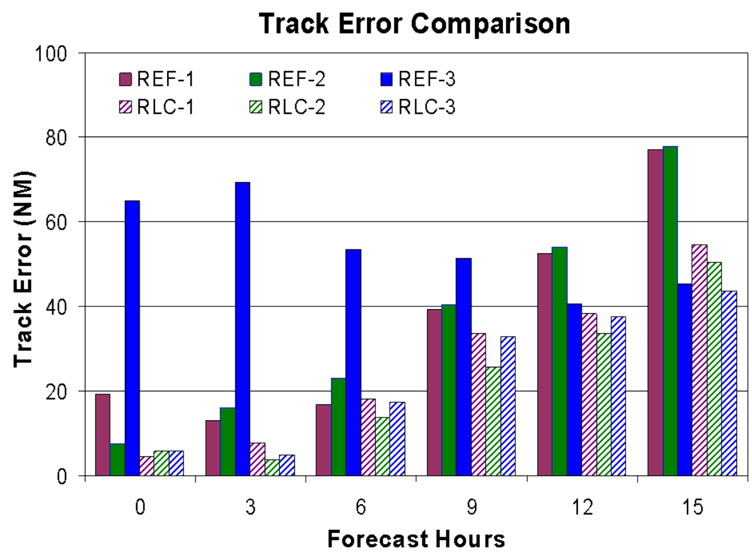

Figure 1. Track error comparison of 15h Katrina forecast by COAMPS before (solid bars) and after (slashed bars) the NAVDAS upgrade. The purple bars are for first mesh (27km resolution), the green bars are for second mesh (9km resolution), and the blue bars are for third moving mesh (3km resolution).

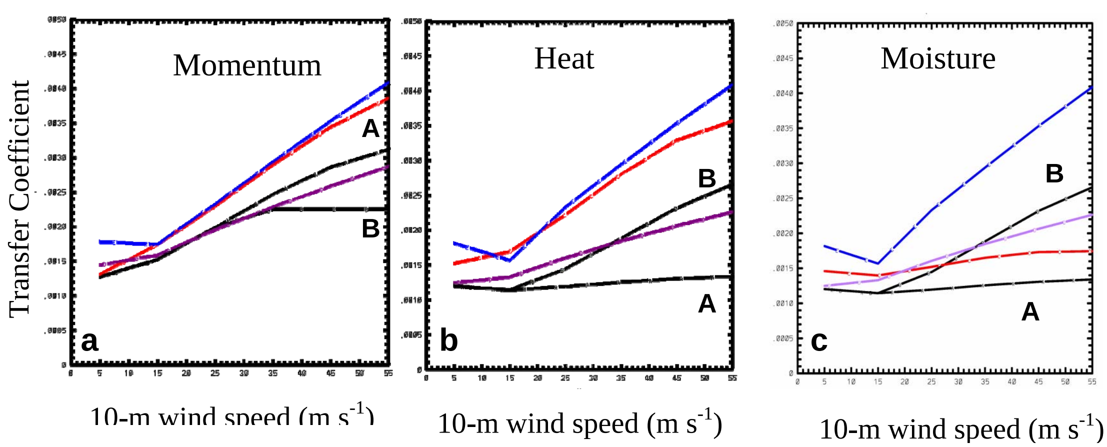

Figure 2. Surface exchange coefficients for (a) momentum, (b) heat, and (c) moisture from the surface schemes used in COAMPS (black line A), WRF ARW (red line), WRF NMM (blue line), and GFDL (purple line). Black line B shows the exchange coefficients from the COAMPS new scheme.

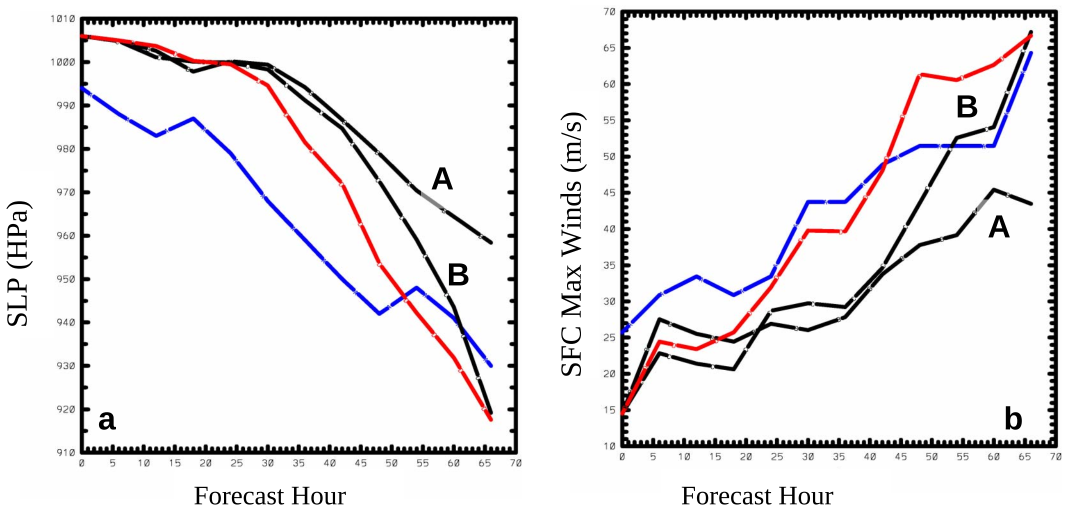

Figure 3. COAMPS simulation results at 3-km resolution for Hurricane Katrina (2005) of (a) minimum sea level pressure (hPa) and (b) surface maximum wind speed (m s-1) using the COAMPS surface scheme (black line A), the COAMPS new scheme (black line B), and the WRF ARW scheme (red line), compared with the NHC best data (blue line).

IMPACT/APPLICATIONS

The development of a high-resolution tropical cyclone (TC) data assimilation and prediction system within COAMPS will give the Navy valuable environmental information that can be applied for conducting missions related to Sea Basing; Intelligence, Surveillance & Reconnaissance; Maritime Operations, Naval Special Warfare; Navigation & SSBN Ops; and Anti-Submarine Warfare,.

TRANSITIONS

The tropical cyclone application of COAMPS will transition to 6.4 projects within PE 0603207N (SPAWAR, PMW-180) that focus on the transition COAMPS to FNMOC.

RELATED PROJECTS

COAMPS will be used in related 6.1 projects within PE 0601153N that include studies of air-ocean coupling and boundary layer studies, and in related 6.2 projects within PE 0602435N that focus on the development of the atmospheric components (QC, analysis, initialization, and forecast model) of COAMPS.

REFERENCES

Hodur, R. M., 1997: The Naval Research Laboratory’s Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS). *Mon. Wea. Rev.*, **125**, 1414-1430.